

Research on Advanced Solid Rocket Launcher

OHTSUKA Hirohito : General Manager, Rocket Systems Department, IHI Aerospace Co., Ltd.

YAGI Kazuhiro : Manager, Rocket Systems Department, IHI Aerospace Co., Ltd.

KISHI Kohichi : Manager, Rocket Systems Department, IHI Aerospace Co., Ltd.

NOHARA Masaru : Manager, Rocket Systems Department, IHI Aerospace Co., Ltd.

SANO Naruhisa : Manager, Rocket Systems Department, IHI Aerospace Co., Ltd.

JAXA has started the research on the Advanced Solid fuel Rocket Launcher (ASRL). IHI Aerospace has been selected as the system integration company of the ASRL development. The ASRL is a successor to the M-V rocket, which has the top performance of the solid rocket launcher in the world. Moreover, the operational performance and cost reduction are targeted mainly in the ASRL development. Small satellites for space science or worldwatch technology demonstration are planned by JAXA and USEF. The ASRL is designed to be best for the small satellite users who have various special demands. The paper describes the summary of general ideas and the development plan of ASRL.

1. Introduction

IHI Aerospace Co., Ltd. (hereinafter called IA) has continued to engage in research and development into solid fuel rocket launchers ever since they first developed pencil rockets. IA has also supported the development of M-V rockets, a type of rocket which uses solid fuels for all stages and was used to launch a planetary probe called “HAYABUSA” (which means “falcon” in Japanese), thus contributing to the advancement of solid rocket launcher system technologies (Fig. 1).

The M-V rockets achieved the world’s highest level of performance, but their high costs meant that they were discontinued after the launch of a solar observation satellite called “HINODE” (which means “sunrise” in Japanese) in September 2006. Solid rockets are highly regarded throughout the world for the small satellites launcher, and the United States is now employing a type of solid rocket called Minotaur, while European countries are

now developing VEGA rocket. Both of these rockets are strategically priced under Official Development Assistance (ODA). It is essential that we see a change in attitude from one valuing performance, to one valuing operability and costs.

Small satellites are more cost-effective than large ones, and there will be demand for small satellites of 1 000 kg or less in the future.⁽¹⁾ In particular, small satellites are expected to contribute to solving global issues such as global warming, because they provide a low-cost demonstration of sensor technologies for observation and data collection on a global scale. Japan has developed two small-satellite programs: one called Small Satellites for Space Science, where a single function will be observed so as to get results in short cycles; and the other called Small Satellites for Technical Demonstrations to establish earth observation technologies (Fig. 2).

Countries in Southeast Asia and other rising nations of space technology have a tendency to use their own small satellites to promote national land conservation, the advancement of science, and the fostering of human resources within each country,⁽²⁾ and these countries require

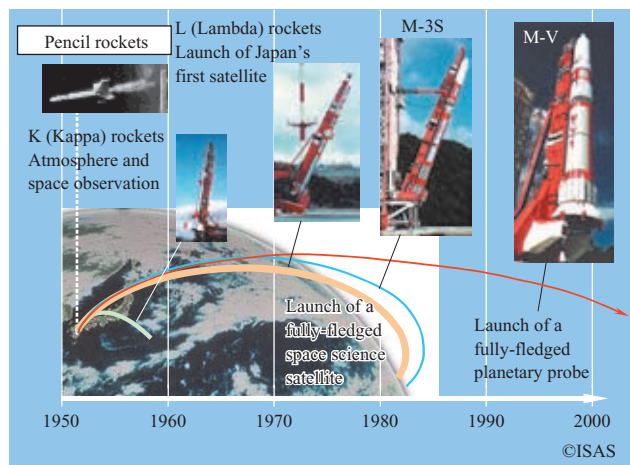


Fig. 1 History of Japanese solid rockets

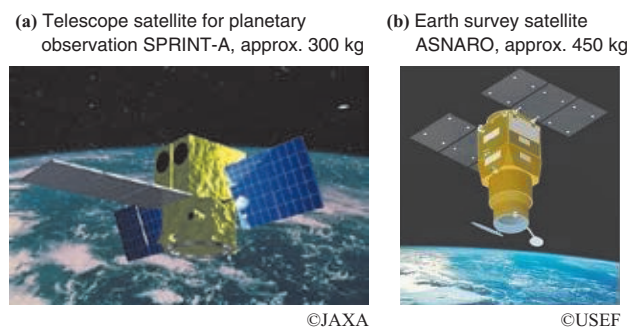


Fig. 2 Japan's small satellite programs

the support of advanced nations of space technology. To respond to the current circumstances both here in Japan and overseas, it is important that we quickly develop new business models through cooperation among governments, satellite manufacturers, and rocket manufacturers.

Small satellites users have some unique requests, such as unique launch operations, unique orbit, late access etc, and there is a great deal of demand for single launches by the unique requests. The characteristics and functions of the Advanced Solid fuel Rocket Launcher (ASRL) are well suited to such special and varied launch demands.

2. Targets for and design of the ASRL⁽³⁾

The Japan Aerospace Exploration Agency (JAXA) began research into the development of the ASRL in order to succeed and raise the M-V rocket system technologies and meet the launch demand for small satellites. IA has been engaged in developing the concept of the ASRL since this research began, aiming to realize a low-cost small-satellite launch system with world-class operability and mobility. The authors have focused the specific key technologies in order to share technologies and components for the principal rocket.

Figure 3 shows an illustration of the ASRL, **Fig. 4** shows its key technologies, and **Fig. 5** shows the target number of working days for ASRL launch sites around the world.

3. Overview of airframe

3.1 Overall configuration and performance data

The basic configuration of the ASRL will be a three-stage solid rocket, with a single-propellant post-boost stage (PBS) available as an optional fourth stage. **Table 1** describes the main characteristics of the ASRL, and **Fig. 6**



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Fig. 3 Illustration of the new ASRL

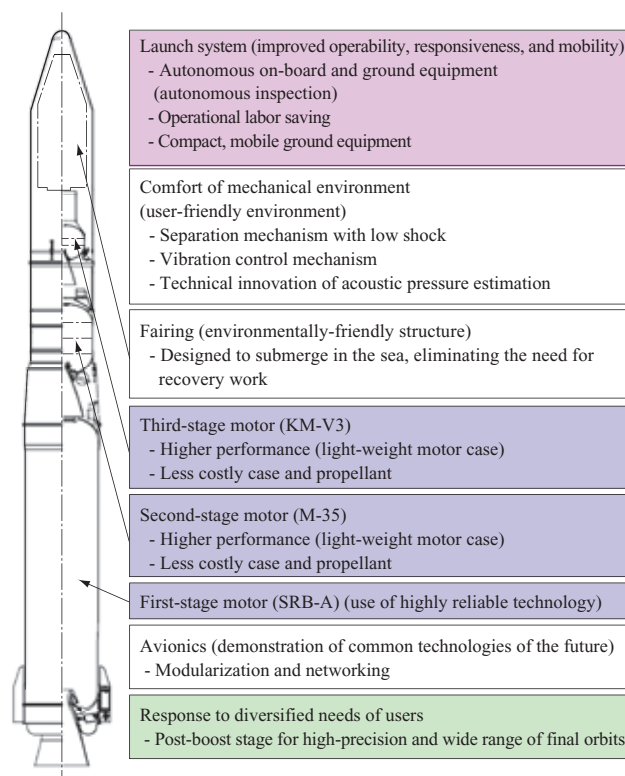


Fig. 4 Key technologies in ASRL development

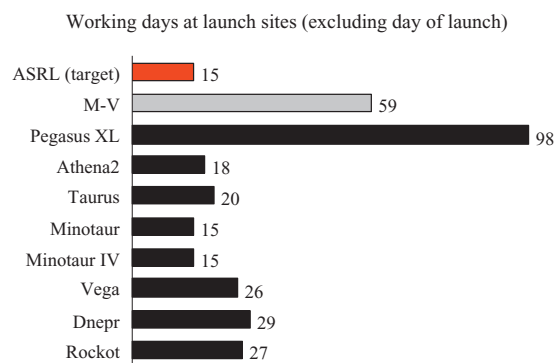



Fig. 5 Targets of working days at launch sites throughout the world

shows the configuration of the ASRL equipped with the optional PBS.

The first stage will use the SRB-A, a solid rocket booster that is used for H-IIA rockets. The second stage and the fairing will have an outer diameter of 2.1 meters, which is smaller than the standard size used for small satellites, to provide improved controllability during first-stage flight and to reduce costs.

This three-stage configuration has been adopted to facilitate the insertion of satellites into the wide variety of orbits requested by satellite users, such as low-earth orbits (LEO), sun-synchronous orbits (SSO), and elliptical orbits. The distribution of propellant weight between the second and third stages will be optimized to enable a satellite to be inserted into any such orbit.

Table 1 Main characteristics of ASRL


Item		Data
Total length		Approx. 25 m
Diameter		2.5 m (First stage) 2.1 m (Second stage)
Weight when fully equipped*1		Approx. 91 t
Stage configuration		Solid three-stage configuration (+PBS)
Orbit insertion performance (Basic configuration)		- Low-earth orbit : 1.2 t - Sun-synchronous transfer orbit : 0.6 t - Elliptical orbit : 0.3 t
First stage	Motor	SRB-A
	Propellant	Polybutadiene composite
	Attitude control	TVC (deflection angle 5 degrees) + SMSJ
	Weight when fully equipped	Approx. 75 t
Second stage	Motor	M-35
	Propellant	Polybutadiene composite
	Attitude control	TVC (deflection angle 1 degrees) + RCS
	Weight when fully equipped*2	Approx. 13 t
Third stage	Motor	KM-V3
	Propellant	Polybutadiene composite
	Attitude control	Spin stabilization
	Weight when fully equipped*1	Approx. 3 t
PBS	Propellant	Hydrazine (single propellant)
	Attitude control	PBS thruster (3-axis)
Guidance control		Inertial guidance

(Note) *1 : Includes PBS but no satellite

*2 : Includes fairing (to be discarded) of 0.6 t

3.2 Overview of airframe

3.2.1 Rocket Structure⁽⁴⁾

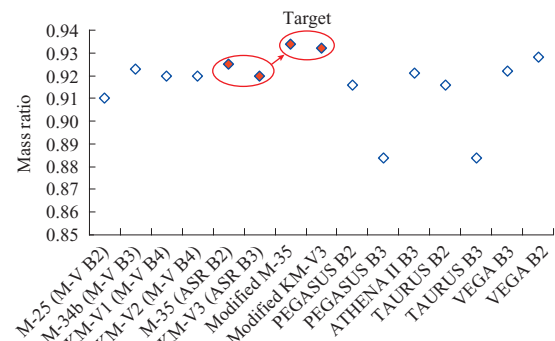
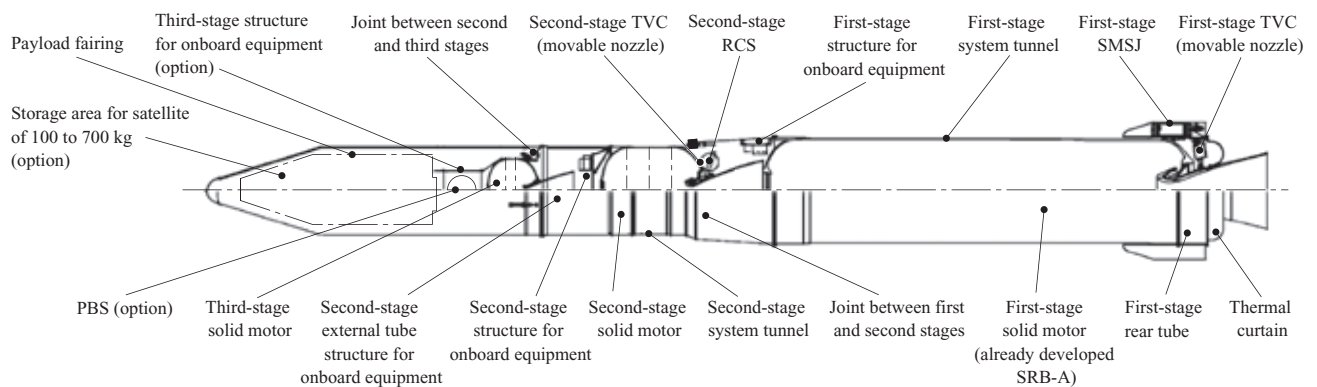
For the first stage structure, the authors decided to use a simple aluminum monocoque structure with a view to reducing the cost of the first stage. For the upper stage, however, the authors focused on performance due to the low impact on upper stage cost. They therefore decided to use light-weight materials such as fiber-reinforced plastic (FRP). The authors also streamlined the manufacturing

processes that will be involved in order to achieve both cost reductions and greater performance, aiming to realize a motor case that offers the highest level of structural efficiency in the world.

Figure 7 shows a comparison of the performances of upper-stage launchers around the world.

3.2.2 Rocket propulsion system⁽⁵⁾

The first stage of the ASRL will be equipped with a highly-reliable SRB-A motor that was originally developed for the H-IIA rocket. For the upper-stage motor, a high-performance propellant that was originally developed for the M-V rocket will be used. The design of the propellant grain shape and the estimation of propulsion performance are based on the design policy behind the M-V rocket. The second stage will be equipped with a newly developed M35 motor, which is almost the same size as the M34b motor used in the third stage of M-V rockets. A high-performance motor will be required for the third stage of the ASRL because it will greatly affect the launch capability. Therefore, the KM-V3 motor mounted in the third stage will have the same head-end grain shape as that of the KM-V2 motor, which was originally developed for M-V rockets, to improve the structural efficiency. The authors have chosen to use ignition from behind to achieve a reduction in weight, and will employ a toroidal igniter that compactly contains a circular primer around the nozzle. This type of igniter is the same as that used for the apogee boost motor (ABM) for H-I rockets.

**Fig. 7** Upper stage mass ratios for launchers around the world**Fig. 6** Configuration of ASRL

3.2.3 Electric system⁽⁶⁾

A lot of time and labor go into conducting inspections and maintenance for rocket electric systems. The authors plan to develop advanced health monitoring, autonomous inspection, and autonomous troubleshooting functions for equipment used on-board the ASRL. They also plan to dramatically improve operability so as to reduce the amount of time required before a launch. With an eye to the future, the authors will expedite the development of high-speed networking (by using space wires, for example) to facilitate communication of various types of information for more advanced autonomous functions and flexible changes in avionics configurations. The authors will also introduce the concept of modularization for technologies common to principal rockets in order to reduce development costs and prevent electric parts shortages by using common circuit boards. As small solid rockets have a relatively higher avionics weight, size, and cost ratio than large principal rockets do, it does not make sense at present to manufacture components for small solid rockets that can be shared with principal rockets. For this reason, the authors plan to promote the modularization of on-board computers, network interface boards, and other functions, as this will enable components manufactured for small solid rockets to be used with principal rockets as well. The authors will also optimize and integrate distributed functions in order to reduce the number of components, thereby reducing costs. By taking these measures, the authors aim to realize small, inexpensive, light-weight avionics that are suitable for small solid rockets.

3.2.4 Control system

(1) Attitude control for the first and second stages

The authors will use the movable nozzle thrust vector control (TVC) method, which became a well-established method in the development of past solid rockets, to provide attitude control for the first and second stages. They will also use electric servo actuators, which are small and have proven to be highly operable. The authors plan to equip the first stage with the electric servo actuators that were originally developed for the SRB-A, while they will equip the second stage with the small motorized actuators that is a partly modified version of the one used for the third stage of M-V rockets.

(2) First-stage roll control and three-axis control

For first-stage roll control and three-axis control, the authors will develop a new controller that is equipped with a solid gas generator similar to the solid motor side jet (SMSJ) used in M-V rockets. The SMSJ that uses a solid gas generator is superior to liquid gas jets as it can be stored for a long time without maintenance. It also has excellent starting performance, enabling it to demonstrate the required performance level as soon as it is started. As the SMSJ generates a large impulse for such a compact body, it is used to control the first stage, which requires a relatively high impulse. M-V rockets were equipped

with two-way valves that allowed injections from two directions and required eight controllers. The authors will equip the ASRL with a three-way valve that requires only two controllers, thereby reducing costs.

Figure 8 shows an illustration of the new SMSJ.

(3) Third-stage attitude stabilization

Instead of using TVC units, the authors will adopt a spin stabilization method to provide attitude stabilization for the third stage in order to achieve cost and weight reductions. When equipped with the optional PBS, the ASRL will be fitted with a Rhumb-line controller to reduce orbit errors before the final stage. This will enable a reduction in the amount of PBS fuel that is required for the final stage.

(4) Post-boost stage (PBS) attitude control

The authors will design the ASRL to allow the option of using a liquid fuel PBS for ASRL's fourth stage in order to improve its orbit insertion accuracy to the same level as that of liquid rockets. It will also be possible to use the PBS acceleration thruster for pitch/yaw attitude control, enabling the number of thrusters to be reduced. The authors will realize a low-cost, highly-reliable PBS by using the thrusters already employed by the reaction control system (RCS) and other devices used for the existing principal rockets.

3.3 Autonomous inspection system⁽⁷⁾

The authors plan to realize autonomous rocket inspections, dramatically improving the efficiency and reliability of inspections and maintenance, both of which require a large number of engineers and a lot of time at present. The authors will also introduce databases for inspections, maintenance, and troubleshooting, all of which are completely reliant on human involvement at present, to reduce the amount of time and labor required for these activities. The authors also plan to develop a device that will be able to inspect ignition circuits in a matter of hours instead of the several days it currently takes as it is dangerous work. This device will be made compact enough to be mounted on-board, reducing the amount of equipment mounted outside the airframe and enabling safe autonomous inspections to be conducted remotely (**Fig. 9**).

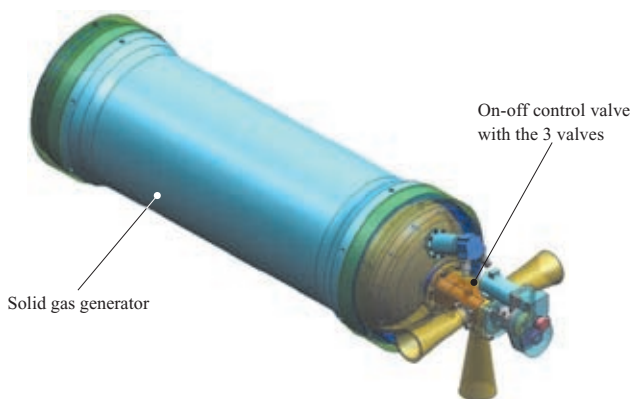


Fig. 8 New SMSJ

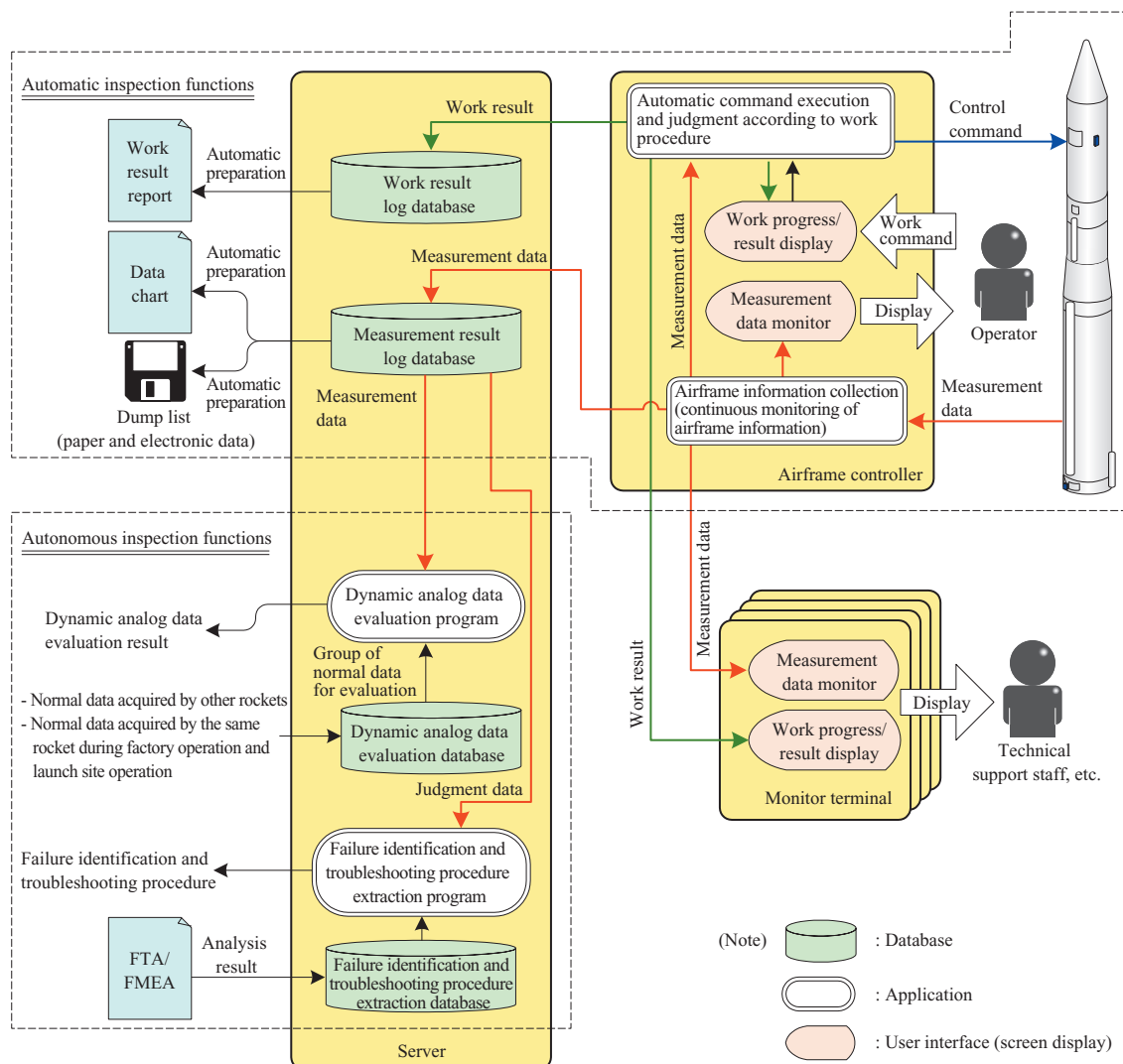
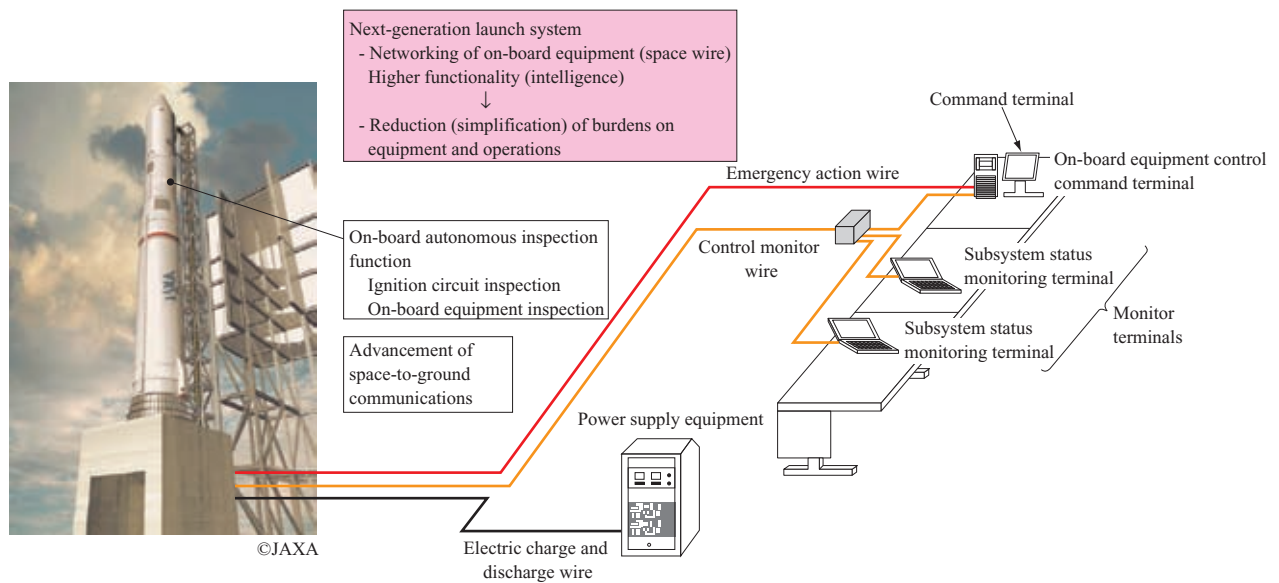


Fig. 9 Intelligent launch operation control system

3.4 Innovative operation plan

(1) Measures to improve operability (responsiveness)⁽⁸⁾

Reducing the amount of work involved in launch-site operations is the key to being able to respond more quickly to user needs (to ensure that satellites are always launched at the right time). The authors will adopt the following measures to reduce the amount of time required for launch-site operations, setting the standard for the rest of the world.

- ① Unitize components to reduce assembly time.
- ② Discontinue the operations refueling RCS tanks at the launch site, adopting instead cartridge-type liquid RCS tanks so that the tanks can be filled with fuel at a factory, transported to the launch site, and then quickly attached to the rocket.
- ③ Develop the launch control system that is compact and mobile in order to realize automated and autonomous functions for launch-site operation management, on-board equipment inspection and troubleshooting, and launch sequence managements by utilizing the information databases. This will enable control operations to be handled by just a few operators (Fig. 10).

(2) Mobile launching pads concept⁽⁹⁾

In addition to the above-mentioned on-board autonomous inspection function and the mobile and compact control system, the authors will develop a movable, simplified launch pad to realize the concept of mobile launch pads that will allow the ASRL to be launched anytime, anywhere. The rocket will be assembled using construction cranes. A simplified cage will be used instead of a conventional large-scale operation building to realize a simplified facility that can be moved anywhere (Fig. 11).

3.5 Advanced information system for rocket development⁽¹⁰⁾

(1) Development process management system

The authors will accumulate enormous technical documents and design know-how acquired in the course of developing the ASRL in the form of a database that will enable technologies to be passed on



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Fig. 10 Launch control system operated by just a few operators



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Fig. 11 Mobile launch pad with a compact cage

to future generations, thus improving the efficiency of future rocket development (Fig. 12).

(2) Mission analysis information system

It takes more than one year from receipt of a request from a satellite user to launch a satellite. To provide many launch opportunities at the right time, the launch cycle time need to be further reduced and significantly reductions need to be made in mission analysis. To this end, the authors will create a database of results from mission analyses conducted for several typical satellites that are to be launched, and compare the data with similar analysis results to reduce the analysis time (Figs. 12 and 13).

4. Future concept

The ASRL will be able to launch microsatellites owned by universities and venture companies promoted by the government. It will provide such users with greater opportunities to launch their satellites, and broaden the availability of space utilization (Fig. 14).

Based on the results of their development of the ASRL, the authors would like to further improve the operability and mobility of small high-efficiency solid rockets that will be developed in the future (Fig. 15).

5. Conclusion

The purposes behind the development of the ASRL are to meet the demand for small satellites used for space science, global environment monitoring, and other fields contributing to the future of mankind, as well as to maintain and further develop solid rocket technologies. The only Japanese manufacturer to have solid rocket system technologies, IA was selected in 2009 as a system manufacturer for the development of the ASRL. Having assumed a great responsibility for the maintenance and advancement of solid rocket technologies, the authors would like to contribute to Japan and the rest of the world through their development of the ASRL and the launching and operation of small satellites.

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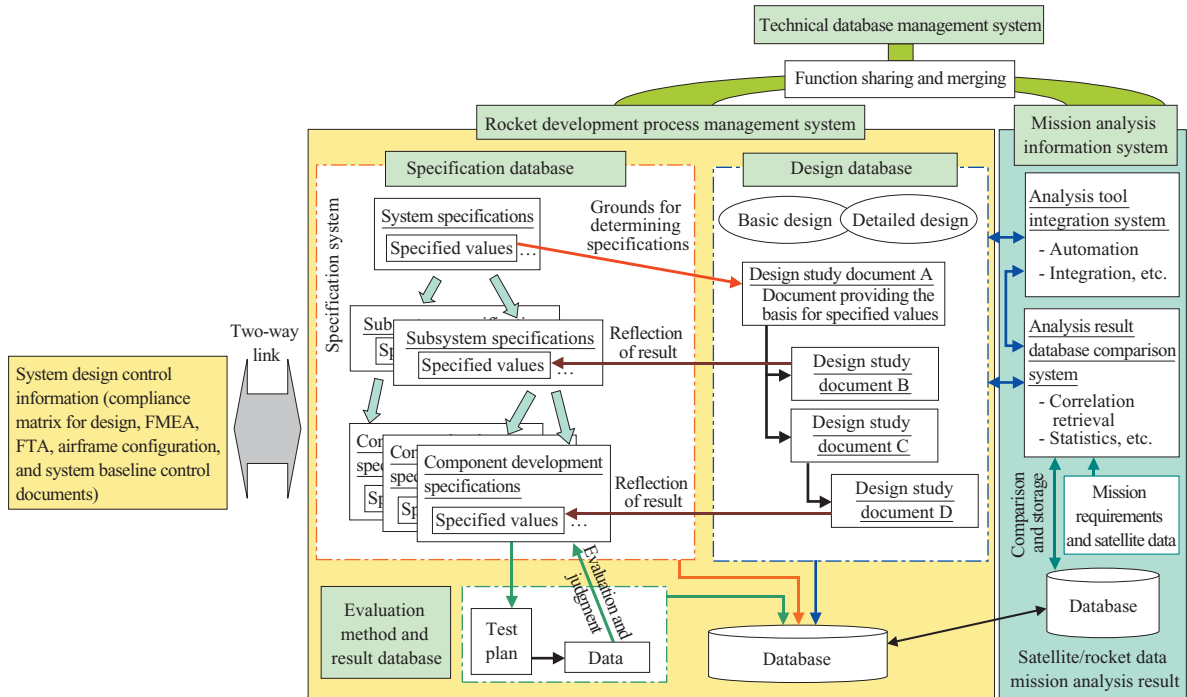


Fig. 12 Intelligent information system for rocket development

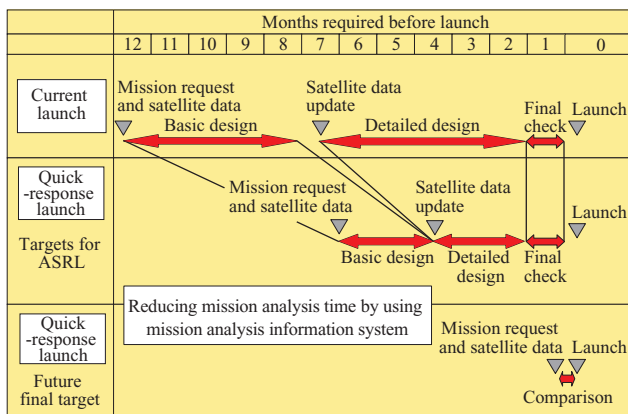


Fig. 13 Reduction of mission analysis time

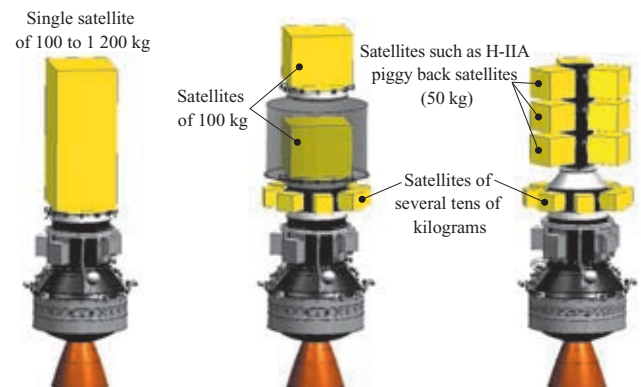


Fig. 14 Launch configurations for microsatellites

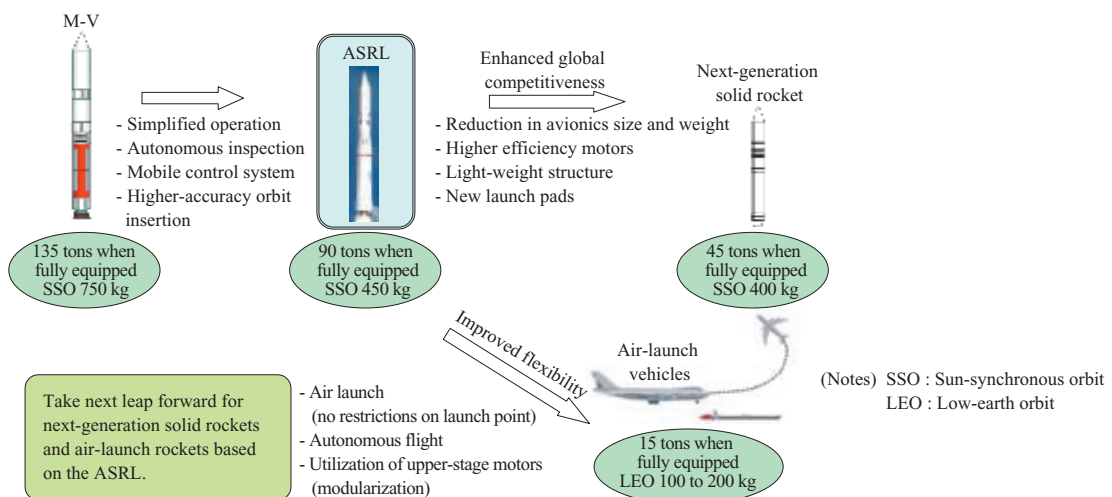


Fig. 15 Road map for small solid rockets

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